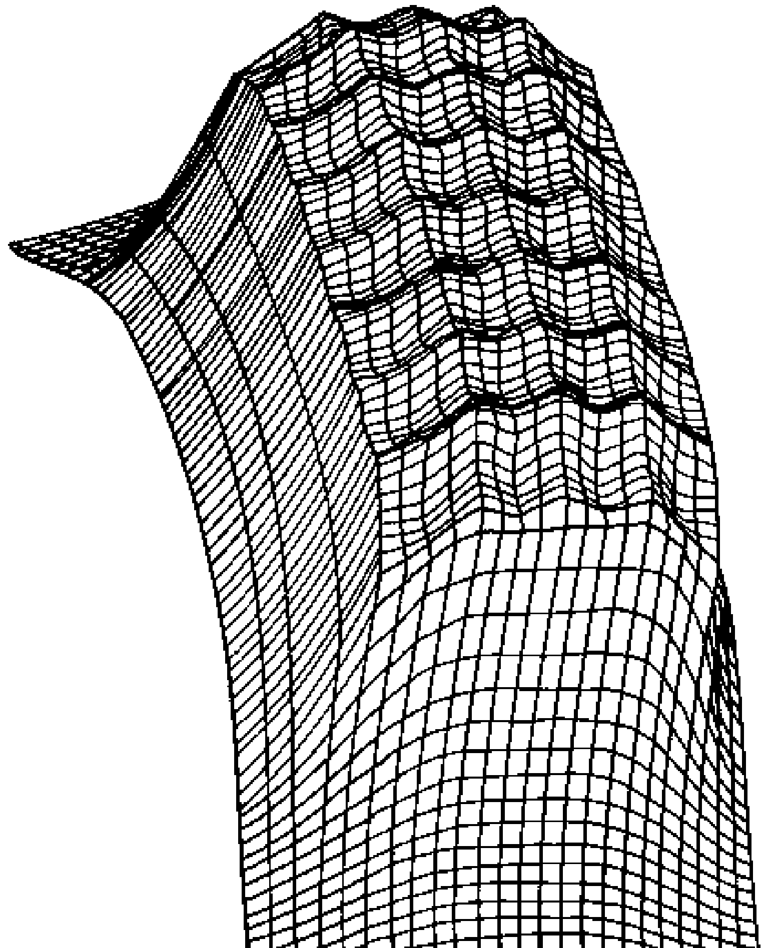
CHAPTER 8

GROUND MAT RESISTANCE TESTING PROCEDURES

February 1990



POWER SYSTEM MAINTENANCE MANUAL

WESTERN AREA POWER ADMINISTRATION

GROUND MAT RESISTANCE TESTING PROCEDURES

FEBRUARY 1990

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CHAPTER 8

Approved for Publication and Distribution

M.F. Groves
Director, Division of
Operation and Maintenance

Date

Disclaimer

Preface

This guide is issued by the Western Area Power Administration (Western) and is designed to provide specific guidelines, instructions, procedures, and criteria for performing ground mat resistance tests in Western's electrical facilities. Procedures and guidelines are in accordance with established industry standards and current industry practices. Any corrections or comments concerning this guide may be addressed to the Western Area Power Administration, A6200, Golden, Colorado.

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1. Introduction

Personnel safety and many aspects of an electrical installation's stable operation are directly related to the adequacy and continued performance of the electrical facility's ground mat. Therefore, Western Area Power Administration (Western) has implemented a ground mat resistance testing program using the fall-of-potential method to determine the adequacy and continued performance of the ground mats that are connected to its electrical facilities.

This document provides the necessary information and criteria needed to establish a safe and effective ground mat testing program in Western. The purpose of this document is twofold: to briefly review the function of ground mats, and to outline, in detail, the recommended ground mat testing procedures. The information contained in this document, when used in conjunction with other applicable safety standards and codes, will provide the necessary information and procedures to perform ground mat tests safely and effectively.

Western will revise and expand this document as needed. Any suggestions that would improve the contents of this document should be sent to Western Headquarters, Division of Operation and Maintenance (O&M), Attn: A6210.

2. General Philosophy

The principal factor in determining the adequacy of a ground mat is its impedance to earth. Designing and achieving a low impedance ground still includes a good deal of both art and science. Impedance is certainly a major consideration in the design of all electrical facilities. However, there are no legislated standards for acceptable ground mat impedance levels at large electrical installations. Instead, the general philosophy is the lower the better, with some consideration of economics.

Western specifications consider acceptable impedance levels as less than 1 ohm for large electrical facilities. Although there can certainly be exceptions in a specific case, it is generally true that a ground mat impedance of 1 ohm will be adequate to:

- Protect personnel and property from injury or damage by high voltage surges resulting from lightning, switching, or other causes.

- Handle discharge currents from lightning arrestors, overvoltage gaps, and so on.

- Provide a ground return path for grounded wye generators and transformers.

- Provide stable ground conditions for protective relays.

- Improve the reliability of electric process controls, computers, and communication circuits by providing low-resistance ground connections.

3. Test Objectives

3.1 General Requirements. From the discussion in section 2, we understand that ground mats are engineered to achieve impedance levels that provide adequate protection and stability for a facility, and once installed they remain physically and electrically stable. Many workers would then ask “So why test an existing ground system?” The following are valid reasons for considering such tests:

- To obtain realistic resistance data for use in calculating actual ground potential rise (GPR) values for the mat, and for determining the step and touch potentials which may occur within a station during fault or surge conditions.
- To help to resolve the instability of equipment relays or communications, which might be caused by inadequate grounding.
- To determine the continued adequacy of the ground mat wherever system changes are implemented which increase the available fault current at the station.
- To determine the effect on the integrity and performance of the ground mat caused by known physical changes (planned or unplanned) in the grounding system.
- To establish ongoing documentation of the stability and continued performance of the grounding system by periodic, scheduled measurement of the ground mat resistance, or, conversely, to detect any unsuspected and undesirable changes.

3.2 Specific Requirements. The following discussion outlines the specific requirements and test intervals for testing Westerns ground mats:

- Field Offices should establish benchmark data for all substation ground mats.
- Ground mats from new electrical facilities will be tested to verify their intended design and adequacy.
- Whenever the ground mat is modified, the ground mat should be tested.
- Ground mats should be tested whenever there is a concern about the continued performance of the grounding system.

4. Test Procedure

4.1 Job Hazard Analysis (JHA). Before testing the ground mat, all personnel involved in the testing must review and discuss the pertinent test procedures of the job hazard analysis (JHA) and address the safety aspects of the testing activity. Western recommends that each Area Office or District Office develop its own specific JHA, using the sample JHA given in appendix A as a guide.

4.2 Equipment. A list of the equipment necessary to perform ground mat resistance testing is included in appendix B. A checklist should be prepared to assure that all the necessary equipment will be on hand when conducting the tests.

Note: Before testing begins, personnel must ensure that all battery-operated instruments (such as the earth tester, the walkie-talkies, and multimeter) are operable and fully charged.

4.3 Preliminary Information. Before beginning the test, the following information must be gathered and recorded on the Ground Mat Resistance Test Report form (shown in appendix C):

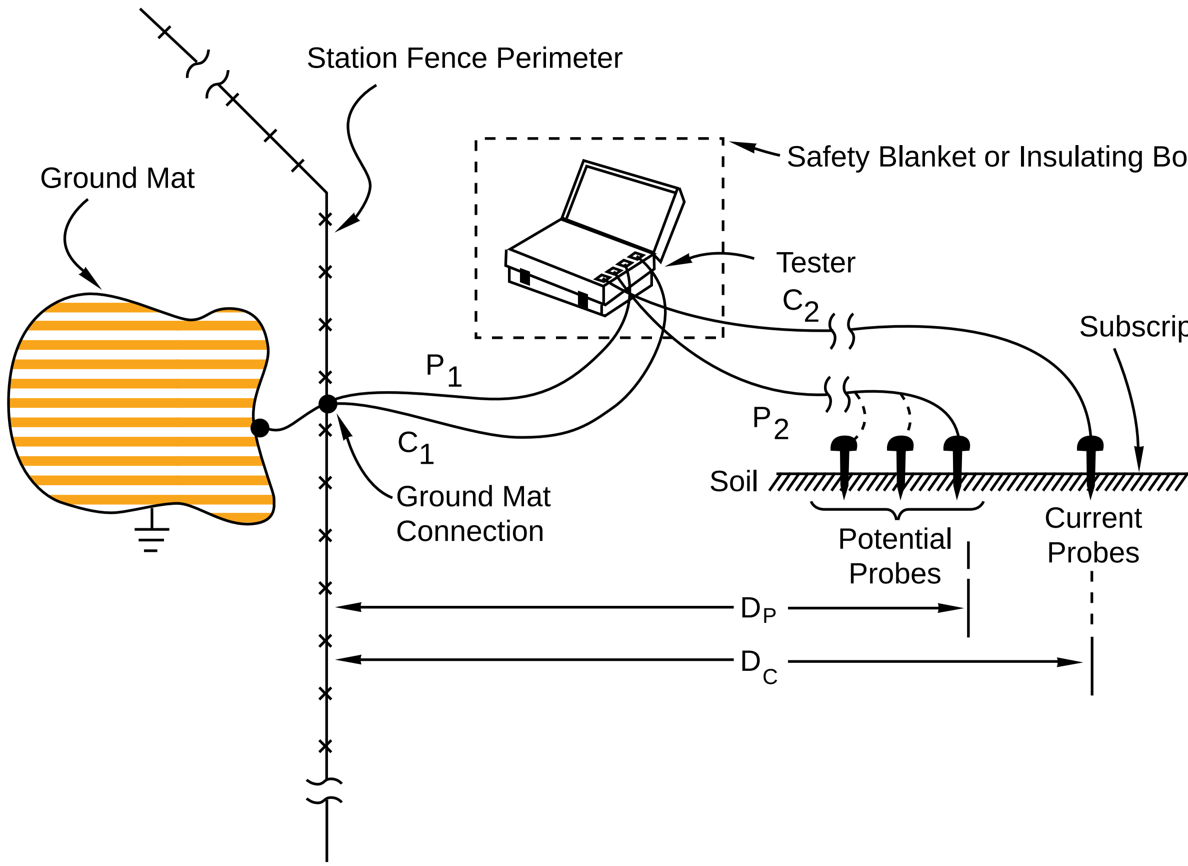
- Station name
- Weather and soil conditions
- Type and serial number of the earth tester
- Current (C2) and potential (P2) probe distances to be used (see section 4.5)
- A sketch of the test area, including special terrain features along the probe directions
- Names of the test coordinator and test engineer
- Tagg Slope tables
- Drawing of the ground plan for the site, including ground mat dimensions
- Notifications, clearances, and gate keys that may be required for working at the site.

4.4 Location of the Tester. The specific location for the tester connection to the ground mat will be selected by the personnel in charge of the test. Generally, the tester will connect at two locations: at a ground riser along the station perimeter fence, or at a ground riser near a piece of equipment located where the terrain surrounding the station permits straight test leads to run for several thousand feet (if possible).

4.5 Routing of the Test Leads. Before setting up the tester, the test engineer will select the direction in which the test leads to the remote C2 and P2 probes shall be run. Routing of the test leads is dependent on the terrain, but they should be run in as straight a line as possible. The first set of data should be taken with the longest practical C2 distance. A rule of thumb is that the distance of C2 equals five times the diagonal of the substation ground mat. The distance of the most distant P2 probe should be greater than 60 percent of the C2 probe distance, preferably at 90 percent. The nearest P2 probe should be placed closer than 20 percent of the C2 distance. The separation between other placed P2 probes should be at equal distances to obtain at least 10 ground mat resistance measurements.

Note: Test leads should not run parallel to transmission or distribution lines, fences, ungrounded piping, and railroads because mutual inductance resulting in the flow of stray currents will affect the test results.

4.6 Initial Test Setup. Personnel should set up the equipment as illustrated in figure 1 and in accordance with the following steps:



Dp = Distance between ground mat system and potential probe.
Dp = Distance between ground mat system and current probe.

Figure 1.

Ground Mat Resistance Testing Setup (Fall-of-Potential Method)

(1) To provide additional insulation to personnel during the test, place an insulating platform or rubber blanket on level ground a short distance from the point of connection to the ground mat (a piece of dry plywood board, 3/4 inch thick, 3 feet wide by 4 feet long, may be used in lieu of a safety blanket). Place the tester on a wooden test stand (if available) and on the blanket or board with the tester oriented so it can be adjusted and read without tripping over the test leads.

(2) Run the C2 and P2 leads to the maximum designated remote test probe distances. **Make sure that the C2 and P2 lead wires are separated by at least 6 feet if they are run parallel with each other.** This arrangement will minimize the mutual inductance between the lead wires while running the test. Other angles between probe leads may be used, but they should be noted on the test report form shown in appendix C.

Note: The leads frequently need to be run several hundred or several thousand feet. Portable two-way radios (walkie-talkies) are essential for maintaining communications between the personnel operating the tester and those running leads or placing probes.

(3) **Make sure the CURRENT RANGE switch on the tester is OFF.**

(4) Drive C2 and P2 probes a few inches into the earth at their maximum designated distances and attach the lead wires. **DO NOT** connect the leads to the tester terminals at this time. Record the distances from the ground mat connection point to the C2 and P2 probes.

Note: It is important that the test probes make good contact with the earth. Tamping the earth around the probe, wetting the earth around the probe, or driving more than one probe and connecting them in parallel are methods of getting the necessary earth contact in problem soils.

(5) Follow the P2 lead back and mark the wire or drop other probes at the distances where the other P2 probe test readings are to be taken. A tape measure should be used to determine the distance between probe placements. The most distant P2 probe should be at a distance greater than 60 percent of the C2 probe distance, preferably at 90 percent. The nearest P2 probe should be placed closer than 20 percent of the C2 distance.

Note: The P2 test points should be in as straight a line toward the tester as the terrain will allow.

4.7 Preliminary Checks. Before continuing, personnel should make the following preliminary checks to assure a proper test setup (a flow chart of the Biddle DET-2 tester operation is illustrated in figure 2):

(1) With P1 disconnected and the CURRENT RANGE switch OFF, connect both P2 and C2 probe leads to their respective terminals on the tester.

(2) Using lineman's gloves, clamp the P1 and C1 tester leads to the ground mat riser cable.

(3) Place the TEST CURRENT dial to NORMAL and FILTER dial to OUT.

(4) Turn the RANGE dial to the 2-ohm position.

(5) If the INPUT NOISE light and the SPIKE RESISTANCE light are off, and the digital numbers are steady (not flickering), then the test setup is good. Turn the RANGE switch to OFF. Proceed to section 4.8 of this procedure.

(6) If the INPUT NOISE light is lit, increase the TEST CURRENT.

(7) If the INPUT NOISE light stays lit at all current levels, the test probe (spike) arrangement must be corrected.

Note: To correct the test probes, one or more of the following steps must be taken:

(a) Moisten the ground around the remote test probes.

(b) Reposition the probes slightly.

(c) Drive one or two additional probes and jumper from probe to probe.

(8) If the SPIKE RESISTANCE light is lit, the test current must be reduced.

(9) If the digital readout flickers, the FILTER switch should be turned to the IN position.

(10) When the tester indicates the setup is good, turn the RANGE switch to OFF and proceed to section 4.8.

4.8. Determining Background Voltages. Measure the ac and dc background voltages as follows to assess any existing stray voltages and currents:

(1) Leave the P1 and C1 leads connected to the ground mat, but disconnect them from the tester (see figure 3).

(2) Connect the ac-dc voltmeter between the C2 probe lead and the C1 lead. Set it for the 0- to 10-volt ac scale.

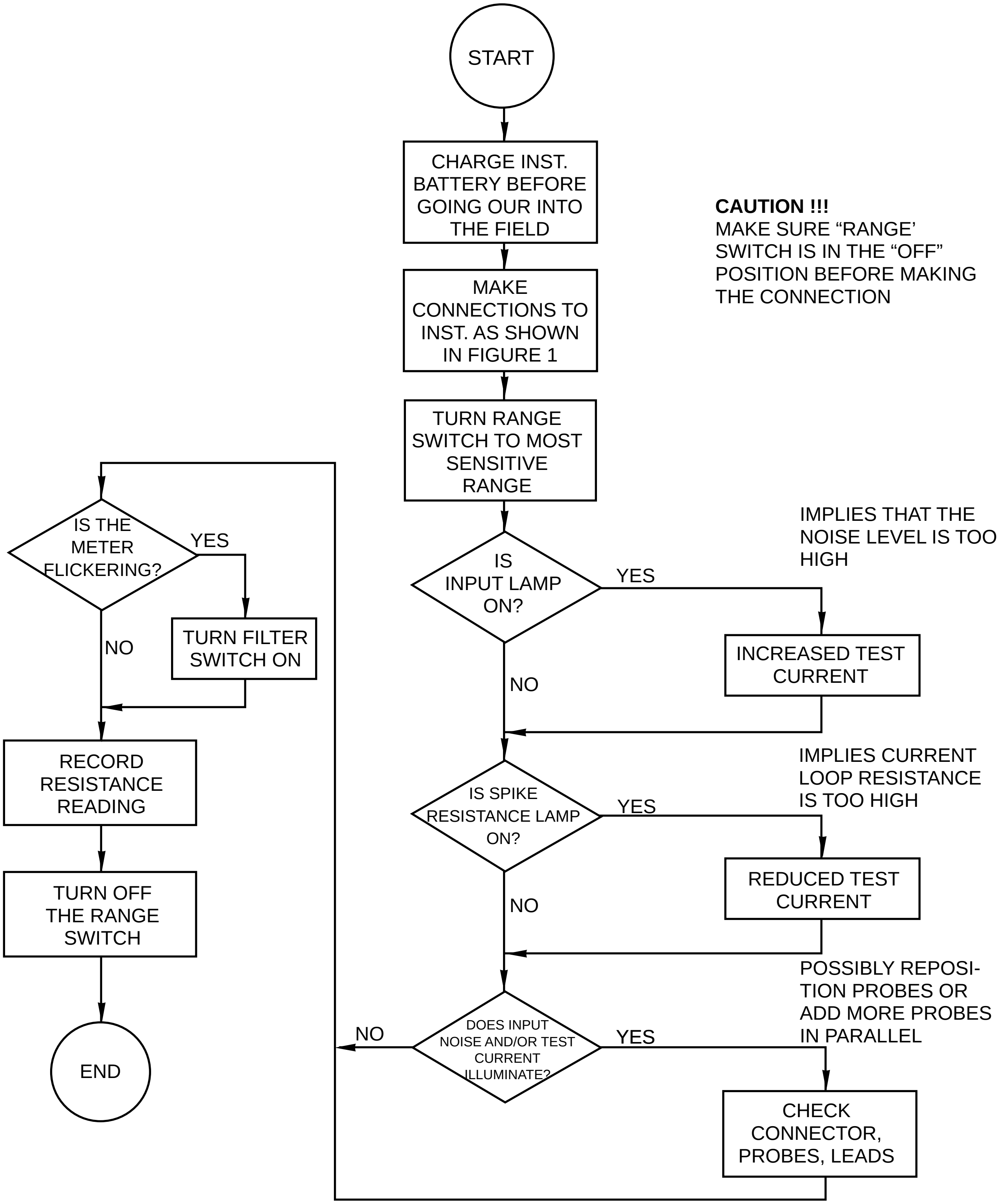


Figure 2.

Flow Chart of Instrument Operation (Biddle DET-2 Earth Tester)

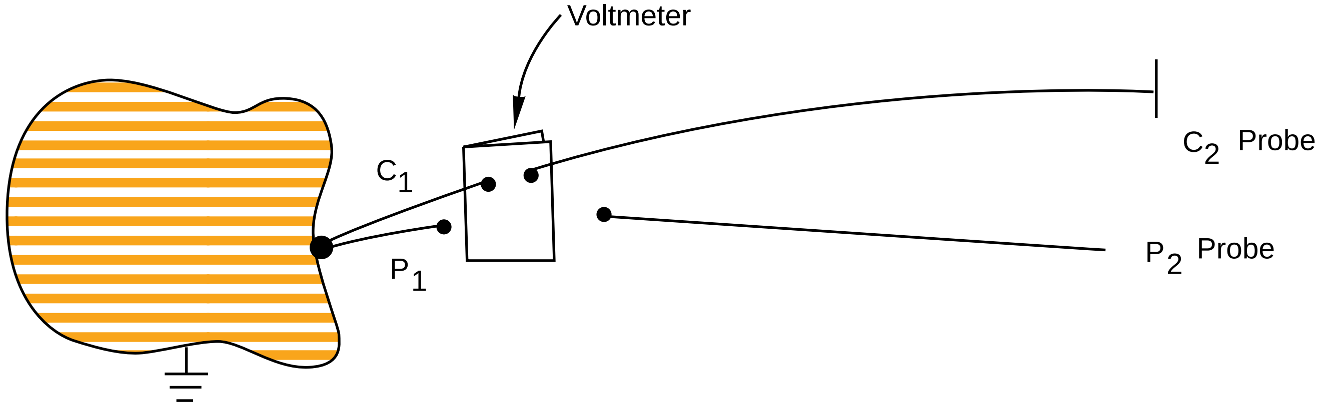


Figure 3.

Measurement of Background Voltages

(3) Read the residual ac voltage and record it on the Ground Mat Resistance Test Report form.

(4) Switch the voltmeter to the dc-volt scale and record the voltage for the C2 lead.

(5) Disconnect the meter from the C2 probe lead and connect it to the P2 probe lead.

(6) Repeat steps 2 through 4 and record the ac and dc voltages for P2.

(7) Disconnect the P1 and C1 leads from the mat. Disconnect the voltmeter.

4.9 Measurement of Resistance to Remote Earth. The following steps outline the specific procedure for making the resistance measurements:

(1) Verify that the RANGE switch on the tester is OFF.

(2) Verify that all connections from tester to ground mat (C1, P1) and to the remote probes (C2, P2) are correct and solid.

(3) Verify that the TEST CURRENT dial on the tester is set to the desired position.

(4) Place station assistants at the remote P2 location and the test engineer at the tester with walkie-talkies to establish communications.

(5) When all personnel are in a safe position and communications are established, turn the RANGE switch to the appropriate setting.

Note: Personnel at the remote probe location should be warned that the instrument is **ON** and not to touch the probes or leads.

(6) Record the ohmic resistance when the reading becomes stable.

(7) Turn the RANGE switch **OFF**.

(8) Disconnect the P2 probe lead from the tester terminal.

(9) Inform the personnel at the remote probe that the tester is disconnected, and request them to move the P2 lead to the next nearest test probe distance.

(10) When the P2 test probe change is confirmed by the remote personnel, connect the P2 probe lead to the tester, turn the RANGE switch to the desired range, and record the ohmic reading for this P2 distance.

(11) Turn the RANGE switch **OFF**.

(12) Repeat steps 8 through 11 for all the designated P2 distances.

(13) Disconnect the P1,C1 leads from the ground mat (wear rubber gloves if connections are made outside the protection zone of the ground mat).

4.10 Verification of Results. The validity of the measurements should be checked at the test site by the following procedure. An example of the calculation procedure is given in appendix D.

(1) Plot measured resistance (ohms) versus the P2 probe distance. (It simplifies the procedure to express the P2 distance as a percentage of the C2 distance.) The curve should be smooth and slightly S-shaped.

(2) From the plot, read the resistance values R1, R2, and R3 corresponding to P2 distances of 0.2, 0.4, and 0.6 C2, respectively.

(3) Calculate $u = (R3 - R2)/(R2 - R1)$.

(4) The value of u should fall within the range 0.40 - 1.60. If it does not fall in this range, the test data is invalid. A new set of test data must be run with C2 at a further distance from the ground mat connection, or with C2 and P2 in a different direction. An alternate approach is to run two more tests with C2 at different distances and to analyze the data by the Tagg Intersecting Curve method (see appendix E).

(5) If u falls within the 0.40 - 1.60 range, find the quantity Pt/EC in the Tagg Slope method tables (see appendix F). This quantity is the P2/C2 value that is associated with the true value of the ground mat resistance.

(6) From the plot of R versus P2/C2, read the true ground mat resistance corresponding to Pt/EC.

4.11 Test Confirmation. At the test coordinator's discretion, other sets of measurements may be taken, as outlined below:

(1) Increase or decrease the C2 probe distance by several hundred feet.

(2) Reposition the P2 probe to approximately 80 percent of the new C2 distance, and mark off distances for the new set of P3 probe placements.

(3) Connect the P2 and C2 probe leads to the tester terminals (verify that the range switch is **OFF**).

(4) Clamp the P1 and C1 test leads to the ground mat cables (wear rubber gloves).

(5) Repeat the series of readings as in section 4.9 with P2 moved successively closer to the ground mat.

(6) Plot this new set of data, check for a smooth curve, and calculate the ground mat resistance according to guidelines given in section 4.10.

Note: The results from the two tests should be within 10 percent if the Tagg Slope method calculation was used. If the Intersecting Curve method was required, the curves should intersect at a value similar to that obtained in other ground mat test results (see the example given in appendix E).

5. Glossary

Background Voltages (ac and dc) Voltage measurements taken between the connection of the grounding system under test and the test instrument end of the C2 and P2 leads.

Current Probe (C2) A probe driven into remote earth used for connecting the current lead routed from the test instrument. This probe allows the test current to enter the ground at the C2 location and circulate current between ground and the test instrument.

Current Test Lead Test lead routed from the test instrument to the remote current probe (C2).

EC The distance between the electrical center of the tested ground system and the remote current probe (C2).

Fall-of-Potential Method The measurement of the voltage between the station ground and remote ground. A test set-up for injecting a current through the station ground via the remote current probe (C2), and measuring the voltage between the station ground and the remote potential probe (P2).

Grounding System The interconnected grounding facilities in a specific area.

Ground Mat A system of closely spaced bare conductors that are connected to the installed system of ground electrodes.

Ground Potential Rise (GPR) The maximum voltage that a station grounding grid may obtain relative to a distant grounding point assumed to be at the same potential as remote earth.

Potential Probe (P2) A probe driven into remote earth used for connecting the potential lead routed from the test instrument. This probe allows the measurement of the voltage produced between the ground system under test and the surface of remote earth.

Potential Test Lead Test lead routed from the test instrument to the remote potential probe (P2).

Pt The calculated distance of P2 where resistance will equal "true" resistance of the tested ground system.

Tagg Slope Method Tables Values of Pt/EC (same as P2/C2) for values of u.

True Resistance The calculated resistance (in ohms) of the tested grounded system.

λ **(lambda)** A letter from the Greek alphabet used to represent the distance of the true electrical center from the tested location.

u **Factor** Ratio of resistance at 60 percent minus the resistance at 40 percent over the resistance at 40 percent minus the resistance at 20 percent (R3 - R2)/(R2 - R1).

6. References

Getting Down to Earth, Biddle Bulletin No. 25Ta.

Guide for the Maximum Electric Power Station Ground Potential Rise and Induced Voltage from a Power Fault, IEEE Std. 367.

Guide for Measuring Earth Resistivity, Ground Impedance, and Earth Surface Potentials of a Ground System, IEEE Std. 81.

Guide for Protection of Wire-line Communication Facilities Serving Electric Power Stations, ANSI/IEEE Std. 487.

Guide for Safety in Substation Grounding, IEEE Std. 80.

IEEE Recommended Practice for Grounding of Industrial and Commercial Power Systems, IEEE Std. 142.

Measurement of the Resistance of an Earth's Electrode System Covering a Large Area, Dr. G. Tagg, IEEE Proceedings, Vol. 116, March 1969.

Measurement of the Resistance of Large Earth Electrode Systems by the Slope Method, Dr. G. Tagg, IEEE Proceedings, Vol. 117, November 1970.

Standard for Grounding Permanent Connections Used in Substation Grounding, ANSI/IEEE Std. 837.

Appendix A

Job Hazard Analysis

JOB HAZARD ANALYSIS

ACTIVITY: Substation Ground Mat
Resistance Measurement Testing

LOCATION: ______________________

JOB HAZARD ANALYSIS NO. Sample

DATE: ______________________

Appendix A

Job Hazard Analysis

The purpose of this document is to address the potential hazards that may be encountered while testing substation ground mats and to list the required countermeasures needed to eliminate such hazards (table A-1).

The information given in this document, when used in conjunction with the information given in other applicable safety standards and codes, should provide the necessary guidance to ensure maximum safety to the public, employees, and property.

A.1 Equipment Operations and Use of Tools. The tests will be conducted in accordance with specific written procedures using the fall-of-potential method (table 4-2). Biddle's Digital Earth Resistance Tester, Model DET-2, will be used to perform the tests. Accessory equipment (used to perform the tests) includes ground rods, test leads, sledgehammer, and a surveyor's level. The instrument's output voltages will be limited to 50 volts peak with selectable test currents of 5 - 40 milliamps.

A.2 System Conditions. The tests will be performed with all electrical conducting paths left connected to the power station grid and with the powerplant operating in its normal configuration.

A.3 Safety Standard Requirements

(1) The tests will be performed according to specific written procedures.

(2) A tailgate safety meeting will be conducted before engaging in the testing to review and discuss the pertinent procedures and to address the safety aspects of the job.

(3) Work activity will be performed under the direction and continuous supervision of experienced personnel who are knowledgeable in the work involved.

(4) Only experienced personnel, knowledgeable in the use and operation of the test set, will be allowed to operate the test instrument.

(5) All personnel will comply with applicable sections of Western's **Power System Safety Manual.**

(6) For safety reasons, workers are encouraged to work in pairs whenever practicable.

(7) A list of emergency telephone numbers for the location where the tests are performed will be available for emergency use (table A-3).

Table A-1. Potential Hazards and Countermeasures

Potential Hazards	Countermeasures
Possible ground faults in the substation while the ground mat testing is underway	Use linemans gloves when handling the test leads. Wear insulated footwear. Avoid placing yourself in series with the test leads while performing the test. Provide fused connections where feasible to enhance safety.
Possible electrical short in the handling of the remotely grounded test leads	Handle leads and probes with caution. Use insulated gloves, rubber-soled shoes, and insulating mat. Disconnect the P_2 lead from the test instrument before allowing anyone to handle the remote leads and ground probes.
Possible electrical shock during the course of the test	If you are involved in the testing, do not come in contact with the cable containing the current probes. Also, caution the public and post any appropriate warning signs.
Poison oak	Be aware of the surroundings and avoid coming in contact with poison oak while setting up the test probes.
Falling while walking over rough terrain	Be aware of the surroundings and walk cautiously. Survey area ahead of time to determine potential hazards. Wear hard hats, safety shoes, and safety glasses.
Changes in normal working environment, such as inclement weather or poor visibility	Assess potential hazards to determine if work can be performed under such conditions or whether to postpone the work until better conditions exist.
Snake bites	Avoid placing the test probes in areas where snakes may nest. Be aware of the surroundings and walk cautiously.
Ticks	In areas where ticks abound during spring and summer months, take appropriate safety measures to avoid tick fever.
Body dehydration	Since routing the test leads involves walking long distances, dehydration may occur. Therefore, have sufficient drinking water available to avoid dehydration.
Vehicle traffic hazards	Place "Men Working" signs when appropriate.

Table A-2. Sample of Written Procedures Approval Sheet

____

SPECIFIC WRITTEN PROCEDURES

1. Are written procedures required? Yes
   If so, is copy attached? Yes

2. If no written procedures are required, please explain why.

____
____
____
____

RESPONSIBLE PERSONNEL:

Signature ______________________ ______________________

Name ______________________ ______________________
(Please Print)

Title ______________________ ______________________

______________________ ______________________

JOB HAZARD ANALYSIS review date: ______________________

____
____

JOB HAZARD ANALYSIS prepared by:

Larry M. Romero, Electrical Engineer,
HQ, Lines and Substations Maintenance
Branch
____

APPROVED BY:

Signature ______________________

Name ______________________
(Please Print)

Title ______________________

Table A-3. List of Emergency Telephone Numbers

Name	Phone Number

Appendix B

Equipment Requirements for Ground Mat Resistance Tests Performed by Fall-of-Potential Method

Appendix B

Equipment Requirements for Ground Mat Resistance Tests Performed by Fall-of-Potential Method

B.1 Test Equipment

- Digital earth tester

- Biddle DET-2 or equivalent earth resistance tester (batteries as required)

- Voltmeter

  Simpson meter, or equivalent, capable of measuring ac and dc in the 0- to 10-volt range

- Lead wire

  5000 feet minimum. In 400- and 800-foot lengths wound on 500- or 1000-foot metal wire reels, with both ends of wire on each reel available for connection to clamps or instrument terminals.

  [Size 14, 16, or 18 AWG, stranded copper with flexible insulating coating (such as SIS type switchboard wire) is recommended.]

- Jumper wires

  Six 2-foot lengths with battery clips on each end. To be used for connecting test probes when more than one probe is required for a good remote ground.

- Test probes

  Eight minimum, 5/8-inch diameter steel, 18 inches long, with pointed tips

- Insulating tester base

  Lineman's blanket or 3/4-inch thick plywood sheet to isolate test personnel from ground while using the tester

- Instrument table

  Wooden table (collapsible) for the tester and test forms

- Wire reel stand with hand crank

  For respooling wire. Should be collapsible and designed to handle two wire spools at a time.

- Two-way radios

  Two portable walkie-talkies with sufficient range and strength to handle anticipated distances and terrain

- Test procedure

- Data forms and graph paper

- Site safety hazard list

B.2 Accessory Equipment

- Tape measure

  Preferably 300-foot steel tape on reel. (Use cloth tape in vicinity of energized equipment.)

- Sledgehammer

  Three- or four-pound, short handle type recommended.

- Clipboard
- Hand calculator
- Linemans gloves
- Compass
- Binoculars
- Leather gloves

B.3 Accessory Tools Kit

- Spare battery clips
- Wire terminals
- Electrical insulation tape
- Side cutters
- Pliers, regular
- Vise grips
- Crimping tool
- Screwdrivers
- Wire brush
- Orange marker tape
- First aid kit
- Flashlight
- Knife

Appendix C

Ground Mat Resistance Test Report Form

Ground Mat Resistance Test Report Form Sheet No. _____ of _____
(Fall-of-potential Method)

FACILITY: ______________________ TEST DATE: ______________________

TEST ENGINEER: ______________________ TEST COORDINATOR: ______________________

WEATHER CONDITION: ______________________ SOIL CONDITION: ______________________

TESTER: ______________________ SERIAL NO.: ______________________

TEST DATA:

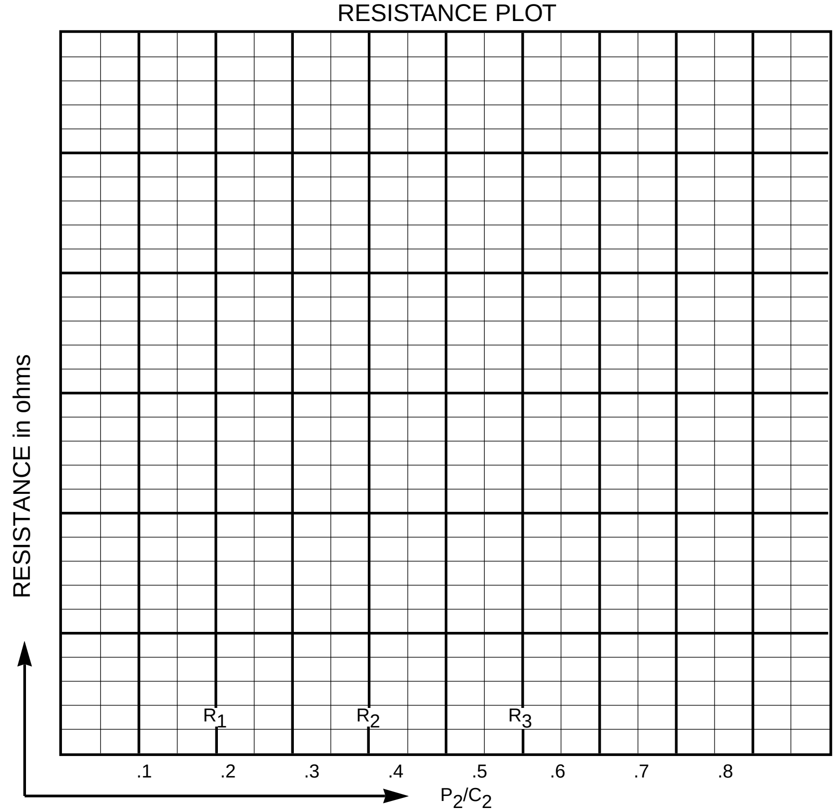
CURRENT ____________ RANGE ____________ FILTER: IN ☐ ; OUT ☐

	DISTANCE	BACKGROUND VOLTAGE	NO. PROBES
Mat to P_2	________ ft.	________ VAC ________ VDC	________
Mat to C_2	________ ft.	________ VAC ________ VDC	________

TEST READINGS:

PROBES			R
C_2.ft	P_2.ft	P_2/C_2	ohms

RESISTANCE PLOT



TEST LAYOUT (North as Shown)

RESISTANCE CALCULATION:

TAGG SLOPE METHOD

$u = \frac{R_3\ R_2}{R_2 - R_1} =$ ____________ =

From Tagg Tables: $\frac{PT}{EC} =$

R True = ohms

NOTES: ____

____

Appendix D

Data Treatment Using the Tagg Slope Method Tables

Appendix D

Data Treatment Using the Tagg Slope Method Tables

Personnel should use this method for validating results in the field and for final analysis of the data.

For example, assume the following test data:

Probe Distances		Measured	
C_2 (feet)	P_2 (feet)	P_2/C_2	R
2,020	1,820	0.90	0.375
2,020	1,620	0.80	0.32
2,020	1,420	0.70	0.295
2,020	1,220	0.60	0.285
2,020	1,020	0.50	0.27
2,020	820	0.41	0.235
2,020	620	0.31	0.215
2,020	420	0.21	0.20
2,020	220	0.11	0.16

Plot measured resistance R versus P_2/C_2 as shown in figure D-1.

Calculate u as follows:

$$u = (R_3 - R_2)/(R_2 - R_1)$$

where

R_3 is taken at $P_2/C_2 = 0.6$

R_2 is taken at $P_2/C_2 = 0.4$

R_1 is taken at $P_2/C_2 = 0.2$.

Thus, from the plot of R vs. P_2/C_2

$$u = (0.285 - 0.245)/(0.245 - 0.190) = 0.727 \quad .$$

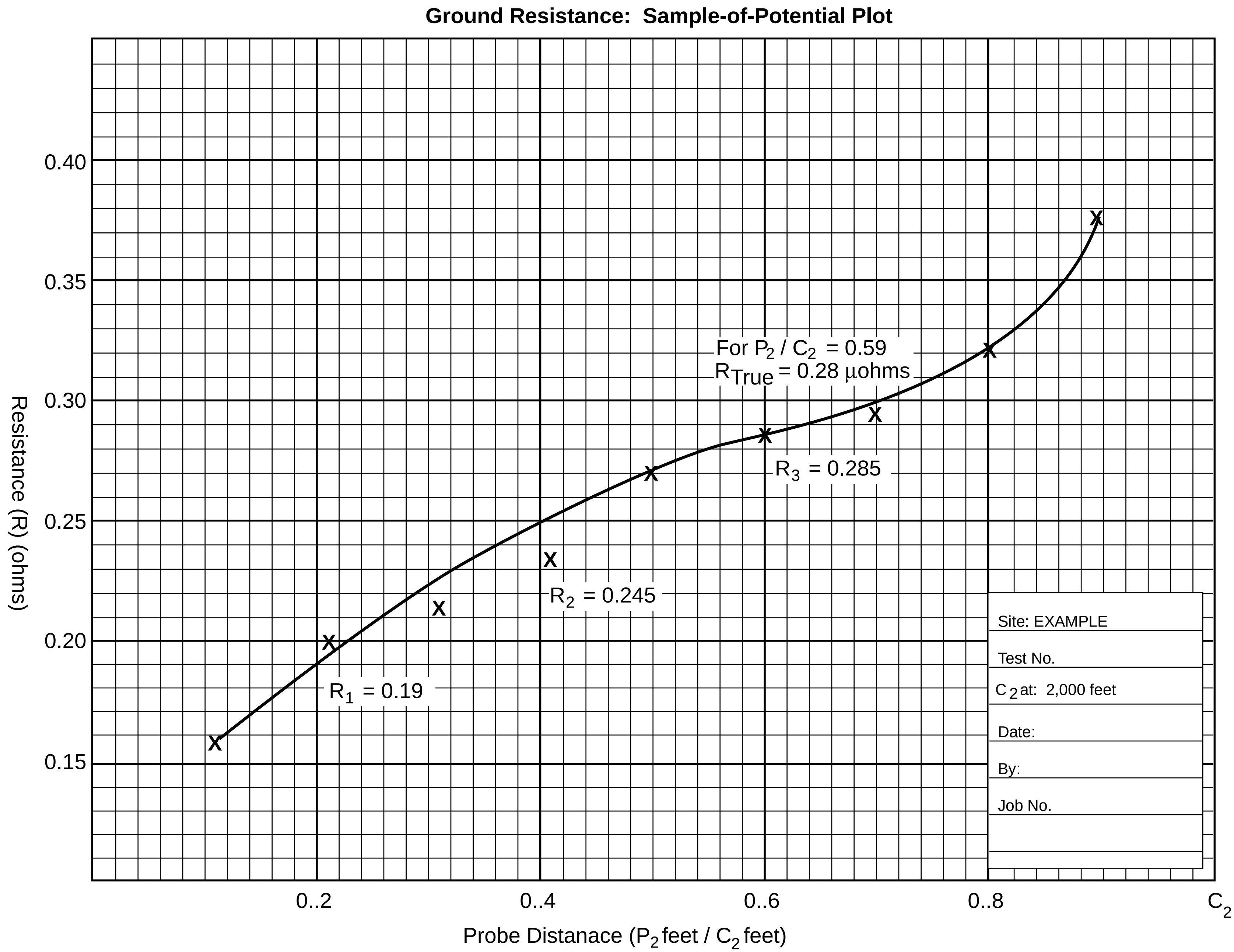


Figure D-1.

Ground Resistance: Sample Fall-of-Potential Plot

From the Tagg Slope tables (appendix F), for u = 0.727,

$$P_t/EC = 0.5928$$

$$(P_t/EC \;=\; P_2/C_2) \quad .$$

Thus, from the R vs. P_2/C_2 plot for P_2/C_2 = 0.59,

$$R = 0.284 \text{ ohms} \quad .$$

If u is outside the range of 0.40 - 1.60, the data cannot be treated in this manner. Instead, personnel should use the Tagg Intersecting Curve method. Appendix E shows how to treat fall-of-potential resistance data by the Tagg Intersecting Curve method.

Appendix E

Data Treatment Using the Intersecting Curve Method

Appendix E

Data Treatment Using the Intersecting Curve Method

When the calculated value of u falls outside the Tagg Slope method tables, then the following procedure can be used (see figure E-1):

(1) Consider that the connection to the ground mat is not at the "electrical center" of the mat (see figure E-1).

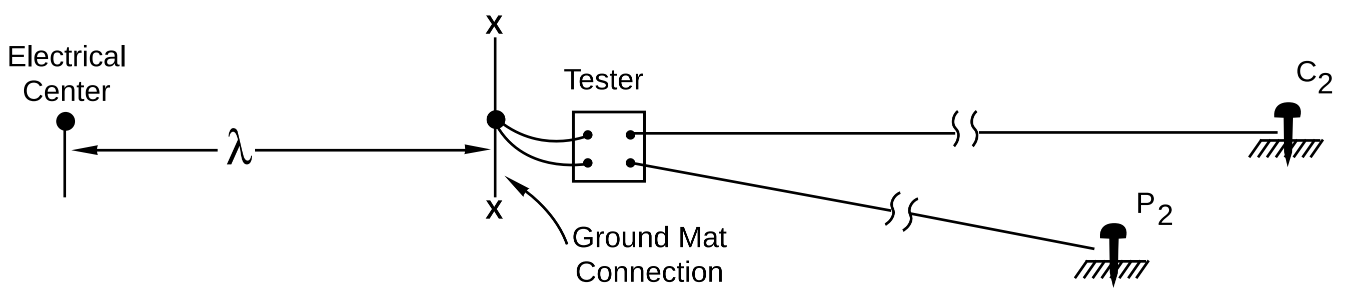


Figure E-1.

Ground Mat Connection

(2) The true C_2 distance should be C2 + λ Then the actual P_2 distance is:

$$P_t = 0.618(C_2 + \lambda) - \lambda = 0.618\, C_2 - 0.382\, \lambda .$$

(3) Calculate P_t for λ equal to 50, 100, 300, 600 feet.

(4) For each calculated value of P_t, choose a value of resistance from the original P_2 vs. R plots (see figure E-2).

(5) Develop a plot of λ vs. R (see figure E-3).

(6) Repeat steps 3-5 for data obtained with the C_2 probe at two (or preferably three) distances. Plot all λ vs. R curves on the same graph (see figure E-3).

(7) The true resistance of the ground mat is the point where the curves intersect.

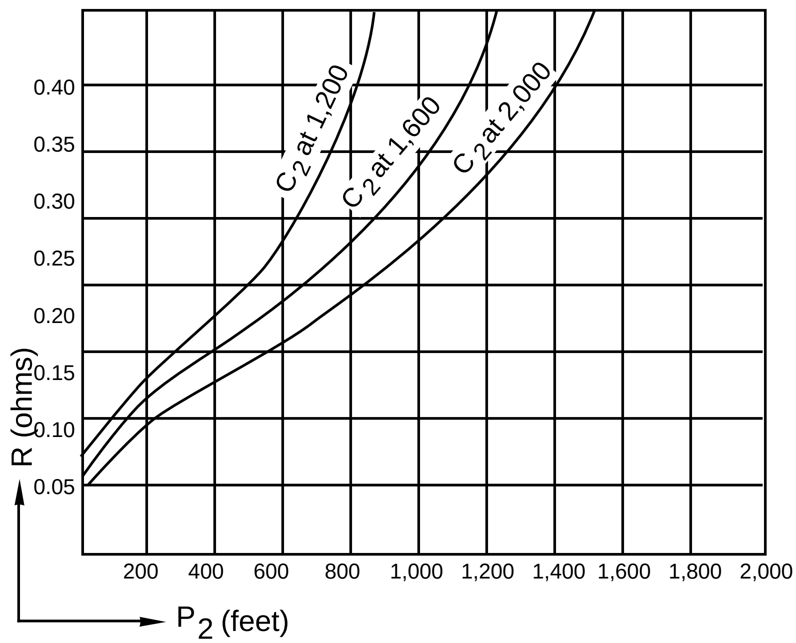


Figure E-2.

P_2 vs. R

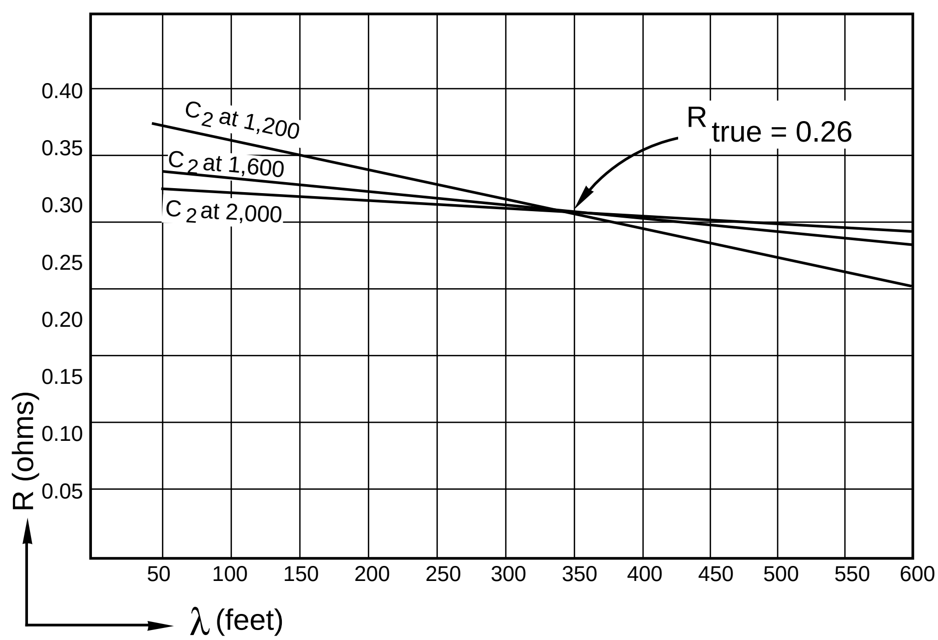


Figure E-3.

λ vs. R

Note: If the intersection of the curves forms a triangle, the true resistance of the ground mat is at the center of the triangle.

An example of this method of treating data is given below:

$$P_t = 0.618\ (C_2 + \lambda\ ) - \lambda = 0.618\ C_2 - 0.382\ \lambda\ .$$

For C_2 at 1,200 feet,

λ (ft)	P_t (ft)	R* (ohms)
50	723	0.32
100	704	0.30
300	627	0.26
600	513	0.20

For C_2 at 1,600 feet,

λ (ft)	P_t (ft)	R (ohms)
50	970	0.29
100	951	0.28
300	874	0.26
600	760	0.23

For C_2 at 2,000 feet,

λ (ft)	P_t (ft)	R (ohms)
50	1,217	0.28
100	1,198	0.27
300	1,121	0.26
600	1,007	0.24

Plotting λ vs. R produces the curves shown in figure E-3. The true ground mat resistance is found at the intersection point, where R = 0.26 ohms.

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*From original P_2 vs. R plots (see figure E-2).

Appendix F

Tagg Slope Method Tables

Tagg Slope Method Tables

(Values of P_t/EC for Values of μ)

μ	0	1	2	3	4	5	6	7	8	9
0.40	0.6432	6431	6429	6428	6426	6425	6423	6422	6420	6419
0.41	0.6418	6416	6415	6413	6412	6410	6409	6408	6406	6405
0.42	0.6403	6402	6400	6399	6397	6396	6395	6393	6392	6390
0.43	0.6389	6387	6386	6384	6383	6382	6380	6379	6377	6376
0.44	0.6374	6373	6372	6370	6369	6367	6366	6364	6363	6361
0.45	0.6360	6359	6357	6356	6354	6353	6351	6350	6348	6347
0.46	0.6346	6344	6343	6341	6340	6338	6337	6336	6334	6333
0.47	0.6331	6330	6328	6327	6325	6324	6323	6321	6320	6318
0.48	0.6317	6315	6314	6312	6311	6310	6308	6307	6305	6304
0.49	0.6302	6301	6300	6298	6297	6295	6294	6292	6291	6289
0.50	0.6288	6286	6285	6283	6282	6280	6279	6277	6276	6274
0.51	0.6273	6271	6270	6268	6267	6265	6264	6262	6261	6259
0.52	0.6258	6256	6255	6253	6252	6250	6248	6247	6245	6244
0.53	0.6242	6241	6239	6238	6236	6235	6233	6232	6230	6229
0.54	0.6227	6226	6224	6223	6221	6220	6218	6217	6215	6214
0.55	0.6212	6210	6209	6207	6206	6204	6203	6201	6200	6198
0.56	0.6197	6195	6194	6192	6191	6189	6188	6186	6185	6183
0.57	0.6182	6180	6179	6177	6176	6174	6172	6171	6169	6168
0.58	0.6166	6165	6163	6162	6160	6159	6157	6156	6154	6153
0.59	0.6151	6150	6148	6147	6145	6144	6142	6141	6139	6138
0.60	0.6136	6134	6133	6131	6130	6128	6126	6125	6123	6121
0.61	0.6120	6118	6117	6115	1663	6112	6110	6108	6107	6105
0.62	0.6104	6102	6100	6099	6097	6096	6094	6092	6091	6089
0.63	0.6087	6086	6084	6083	6081	6079	6077	6076	6074	6073
0.64	0.6071	6070	6068	6066	6065	6063	6061	6060	6058	6057
0.65	0.6055	6053	6052	6050	6049	6047	6045	6044	6042	6040
0.66	0.6039	6037	6036	6034	6032	6031	6029	6027	6026	6024
0.67	0.6023	6021	6019	6018	6016	6015	6013	6011	6010	6008
0.68	0.6006	6005	6003	6002	6000	5998	5997	5995	5993	5992
0.69	0.5990	5989	5987	5985	5984	5982	5980	5979	5977	5975

μ	0	1	2	3	4	5	6	7	8	9
0.70	0.5974	5973	5971	5969	5967	5965	5964	5962	5960	5959
0.71	0.5957	5955	5953	5952	5950	5948	5947	5945	5943	5942
0.72	0.5940	5938	5936	5935	5933	5931	5930	5928	5926	5924
0.73	0.5923	5921	5920	5918	5916	5914	5912	5911	5909	5907
0.74	0.5906	5904	5902	5900	5899	5897	5895	5894	5892	5890
0.75	0.5889	5887	5885	5883	5882	5880	5878	5877	5875	5873
0.76	0.5871	5870	5868	5866	5865	5863	5861	5859	5858	5856
0.77	0.5854	5853	5851	5849	5847	5846	5844	5842	5841	5839
0.78	0.5837	5835	5834	5832	5830	5829	5827	5825	5824	5822
0.79	0.5820	5818	5817	5815	5813	5812	5810	5808	5806	5085
0.80	0.5803	5801	5799	5797	5796	5794	5792	5790	5788	5786
0.81	0.5785	5783	5781	5779	5777	5775	5773	5772	5770	5768
0.82	0.5766	5764	5762	5760	5759	5757	5755	5753	5751	5749
0.83	0.5748	5746	5744	5742	5740	5738	5736	5735	5733	5731
0.84	0.5729	5727	5725	5723	5722	5720	5718	5716	5714	5712
0.85	0.5711	5709	5707	5705	5703	5701	5699	5698	5696	5694
0.86	0.5692	5690	5688	5686	5685	5683	5681	5679	5677	5675
0.87	0.5674	5672	5670	5668	5666	5664	5662	5661	5659	5657
0.88	0.5655	5653	5651	5650	5648	5646	5644	5642	5640	5638
0.89	0.5637	5635	5633	5631	5629	5627	5625	5624	5622	5620
0.90	0.5618	5616	5614	5612	5610	5608	5606	5604	5602	5600
0.91	0.5598	5596	5594	5592	5590	5588	5586	5584	5582	5580
0.92	0.5578	5576	5574	5572	5570	5568	5565	5563	5561	5559
0.93	0.5557	5555	5553	5551	5549	5547	5545	5543	5541	5539
0.94	0.5537	5535	5533	5531	5529	5527	5525	5523	5521	5519
0.95	0.5517	5515	5513	5511	5509	5507	5505	5503	5501	5499
0.96	0.5497	5495	5493	5491	5489	5487	5485	5483	5481	5479
0.97	0.5477	5475	5473	5471	5469	5467	5464	5462	5460	5458
0.98	0.5456	5454	5452	5450	5448	5446	5444	5442	5440	5438
0.99	0.5436	5434	5432	5430	5428	5426	5424	5422	5420	5418

Tagg Slope Method Tables (concluded)

(Values of P_t/EC for Values of μ)

μ	0	1	2	3	4	5	6	7	8	9
1.00	0.5416	5414	5412	5409	5407	5405	5403	5400	5398	5396
1.01	0.5394	5391	5389	5387	5385	5383	5380	5378	5376	5374
1.02	0.5371	5369	5367	5365	5362	5360	5358	5356	5354	5351
1.03	0.5349	5347	5345	5342	5340	5338	5336	5333	5331	5329
1.04	0.5327	5325	5322	5320	5318	5316	5131	5311	5309	5307
1.05	0.5305	5302	5300	5298	5296	5293	5291	5289	5287	5284
1.06	0.5282	5280	5278	5276	5273	5271	5269	5267	5264	5262
1.07	0.5260	5258	5255	5253	5251	5249	5247	5244	5242	5240
1.08	0.5238	5235	5233	5231	5229	5226	5224	5222	5219	5217
1.09	0.5215	5213	5211	5209	5206	5204	5202	5200	5197	5195
1.10	0.5193	5190	5188	5185	5183	5180	5178	5175	5173	5170
1.11	0.5168	5165	5163	5160	5158	5155	5153	5150	5148	5145
1.12	0.5143	5140	5137	5135	5132	5130	5127	5125	5122	5120
1.13	0.5118	5115	5113	5110	5108	5105	5103	5100	5098	5095
1.14	0.5093	5090	5088	5085	5083	5080	5078	5075	5073	5070
1.15	0.5068	5065	5062	5060	5057	5055	5052	5050	5047	5045
1.16	0.5042	5040	5037	5035	5032	5030	5027	5025	5022	5020
1.17	0.5017	5015	5012	5010	5007	5005	5002	5000	4997	4995
1.18	0.4992	4990	4987	4985	4982	4980	4977	4975	4972	4970
1.19	0.4967	4965	4962	4960	4957	4955	4952	4950	4947	4945
1.20	0.4942	4939	4936	4933	4930	4928	4925	4922	4919	4915
1.21	0.4913	4910	4907	4904	4901	4899	4896	4893	4890	4887
1.22	0.4884	4881	4878	4875	4872	4870	4867	4854	4861	4858
1.23	0.4855	4852	4849	4846	4843	4841	4838	4835	4832	4829
1.24	0.4825	4823	4820	4817	4814	4812	4809	4806	4803	4800
1.25	0.4797	4794	4791	4788	4785	4783	4780	4777	4774	4771
1.26	0.4768	4765	4762	4759	4756	4754	4751	4748	4745	4742
1.27	0.4739	4736	4733	4730	4727	4725	4722	4719	4716	4713
1.28	0.4710	4707	4704	4701	4698	4696	4693	4690	4687	4684
1.29	0.4681	4678	4675	4672	4669	4667	4664	4661	4658	4655

μ	0	1	2	3	4	5	6	7	8	9
1.30	0.4652	4649	4645	4642	4638	4635	4631	4628	4625	4621
1.31	0.4618	4614	4611	4607	4604	4601	4597	4594	4590	4586
1.32	0.4583	4580	4577	4573	4570	4566	4563	4559	4556	4553
1.33	0.4549	4546	4542	4539	4535	4532	4529	4525	4522	4518
1.34	0.4515	4511	4508	4505	4501	4498	4494	4491	4487	4484
1.35	0.4481	4477	4474	4470	4467	4463	4460	4457	4453	4450
1.36	0.4446	4443	4439	4436	4432	4429	4426	4422	4419	4415
1.37	0.4412	4408	4405	4402	4398	4395	4391	4388	4384	4381
1.38	0.4378	4374	4371	4367	4364	4360	4357	4354	4350	4347
1.39	0.4343	4340	4336	4333	4330	4326	4323	4319	4316	4312
1.40	0.4309	4305	4301	4296	4292	4288	4284	4280	4275	4271
1.41	0.4267	4263	4258	4254	4250	4246	4242	4237	4233	4229
1.42	0.4225	4221	4216	4212	4208	4204	4200	4195	4191	4187
1.43	0.4183	4178	4174	4170	4166	4162	4157	4153	4149	4145
1.44	0.4141	4136	4132	4128	4124	4210	4115	4111	4107	4103
1.45	0.4099	4094	4090	4086	4082	4077	4073	4069	4065	4061
1.46	0.4056	4052	4048	4044	4040	4035	4031	4027	4023	4018
1.47	0.4014	4010	4005	4001	3997	3993	3989	3985	3980	3976
1.48	0.3972	3968	3964	3959	3955	3951	3947	3943	3938	3934
1.49	0.3930	3926	3921	3917	3913	3909	3905	3900	3896	3892
1.50	0.3888	3883	3878	3874	3869	3864	3859	3854	3850	3845
1.51	0.3840	3835	3830	3825	3820	3816	3811	3806	3801	3796
1.52	0.3791	3786	3781	3776	3771	3766	3760	3755	3750	3745
1.53	0.3740	3735	3730	3724	3719	3714	3709	3704	3698	3693
1.54	0.3688	3683	3677	3672	3667	3662	3656	3651	3646	3640
1.55	0.3635	3630	3624	3619	3613	3608	3602	3597	3591	3586
1.56	0.3580	3574	3569	3563	3557	3552	3546	3540	3534	3528
1.57	0.3523	3517	3511	3506	3500	3494	3488	3482	3477	3471
1.58	0.3465	3459	3453	3447	3441	3435	3429	3423	3417	3411
1.59	0.3405	3399	3393	3386	3380	3374	3368	3362	3355	3349